

## **Evaluation of Coatings for FR-4 Fiberglass Epoxy Composite Probes**

**by Faye R. Toulan, David P. Flanagan, John J. La Scala, and  
Daniel M. De Bonis**

**ARL-TR-6771**

**January 2014**

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## 1. Introduction

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The Explosive Ordnance Disposal (EOD) Soldiers are the U.S. Army's tactical and technical explosive experts. One tool they use to investigate potential explosive devices is a handheld probe fabricated from FR-4 fiberglass epoxy composite. In an effort to protect the probe from the damaging effects of abrasive components in soil, commercial coatings were evaluated for wear resistance. This report focuses on the application and performance properties of coatings applied to the FR-4 fiberglass epoxy composite material.

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## 2. Materials

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### 2.1 Coatings

Rust-Oleum Specialty Appliance Epoxy is a hard-spray-applied, moisture-resistant enamel that is specifically formulated for indoor metal surfaces. It provides a smooth, washable surface for refinishing the exterior of appliances, such as refrigerators, dishwashers, laundry machines, dryers, and other indoor metal applications, such as tables or cabinets (1). This product contains 519 g/L volatile organic compound (VOC) (2).

3M Scotchkote<sup>\*</sup> Epoxy Ceramic Surfacers FG-512 has been specifically developed as a ceramic-enhanced epoxy repair coating for resurfacing and reforming metal machinery and equipment, such as pumps, impellers, fans, valves, and pipe elbows (3). This product is designed for application by a stiff brush or squeegee. It also provides outstanding resistance to impingement, entrainment, and erosion/corrosion. When parts A and B are mixed, the VOC content is 0 g/L (4).

CeRam-Kote 54<sup>†</sup> is a thin-film, spray-applied, and air-cured ceramic coating engineered to provide excellent abrasion and corrosion protection in critical service environments for all metals, fiberglass-reinforced plastics, composites, and plastic substrates (5). CeRam-Kote 54 is a highly modified epoxy resin system that has been heavily loaded with a unique package of ceramic particles to enhance performance in extremely aggressive environments. This product contains 196 g/L VOC (6).

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<sup>\*</sup>Scotchkote is a registered trademark of 3M.

<sup>†</sup>CeRam-Kote 54 is a registered trademark of Ceram-Kote Coating, Inc.

## 2.2 Probe/Substrate

The probe is fabricated from a composite material (FR-4) composed of woven fiberglass cloth with a flame-resistant epoxy resin binder. FR-4 is a grade designation assigned to glass-reinforced epoxy laminate sheets, tubes, rods, and printed circuit boards (7). FR-4 fiberglass epoxy composite meets the military specification MIL-I-24768/27 (8). The blade of the probe measures 8 in long  $\times$  1.25 in wide  $\times$  approximately 0.375 in thick with a 5-in-long handle (figure 1). The substrate used for testing was fabricated from identical materials as the probe. The dimensions of the composite substrate were 4  $\times$  4  $\times$  0.375 in. There was a 0.125-in-deep counter-sinkhole drilled into the center of the substrate to accommodate the testing equipment (figure 1).



Figure 1. Composite probe and test substrate.

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## 3. Experimental Method

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The *Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser* (ASTM D4060-10) was used as a guide (9). This test method covers the determination of the resistance of organic coatings to abrasion produced by the Taber Abraser on coatings applied to a plane rigid surface (9). Taber Abraser model number 5135 was used to evaluate the coatings (figure 2).



Figure 2. Taber Abraser model 5135. (Image used with the permission of Taber Industries.)

The Taber is a single rotary platform that performs accelerated wear/abrasion testing. Prior to coating, the substrates were prepared by grit blasting with 180 aluminum oxide. All coatings were applied by spray or brush to the substrate and allowed to cure for a minimum of 1 week at ambient temperature prior to testing. The composite substrate ( $4 \times 4 \times 0.375$  in) with coating was mounted to a turntable platform that rotates on a vertical axis (10). The test interval was 1000 cycles rotating at a speed of 60 cycles/min. Three samples per coating were prepared for this test series. Taber CS-10 abrasive wheels, which were applied at a load of 1 kg each, were lowered onto the specimen surface. The Calibrase<sup>\*</sup> wheel CS-10 is designated for medium abrading action and is standard for coatings (10). The abrading wheels were resurfaced after every 1000-cycle interval. Characteristic rub-wear action is produced by contact of the test specimen against the sliding rotation of the two abrading wheels. As the turntable rotates, the wheels are driven by the sample in opposite directions about a horizontal axis displaced tangentially from the axis of the sample (figure 3). One abrading wheel rubs the specimen outward toward the periphery, and the other rubs inward toward the center while a vacuum system removes loose debris during the test. The wheels traverse a complete circle on the specimen surface, revealing abrasion resistance at all angles relative to the grain of the material. The resulting abrasion marks form a pattern of crossed arcs in a circular band that covers an area approximately  $30 \text{ cm}^2$  (10).

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<sup>\*</sup> Calibrase is a trademark of Taber Industries.

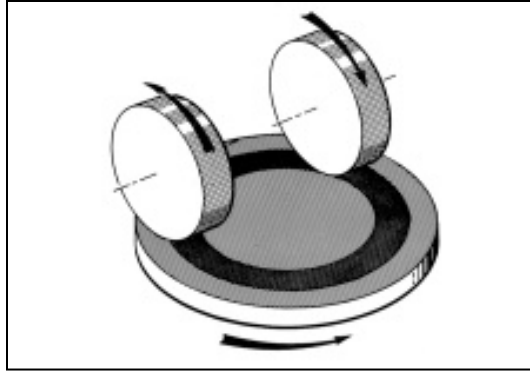


Figure 3. Taber rotary test configuration. (Image used with the permission of Taber Industries.)

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## 4. Results and Discussion

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Both Rust-Oleum (figure 4) and CeRam-Kote 54 (figure 5) were applied by spray and produced a thin film. This thin film allows coverage of the probe while maintaining the rigid sharp edge. The 3M FG-512 (figure 6) was applied by brush and created a slightly thicker and uneven coating. Because of the irregularities in the 3M FG-512 coating, the probe edge may not be as sharp after application.

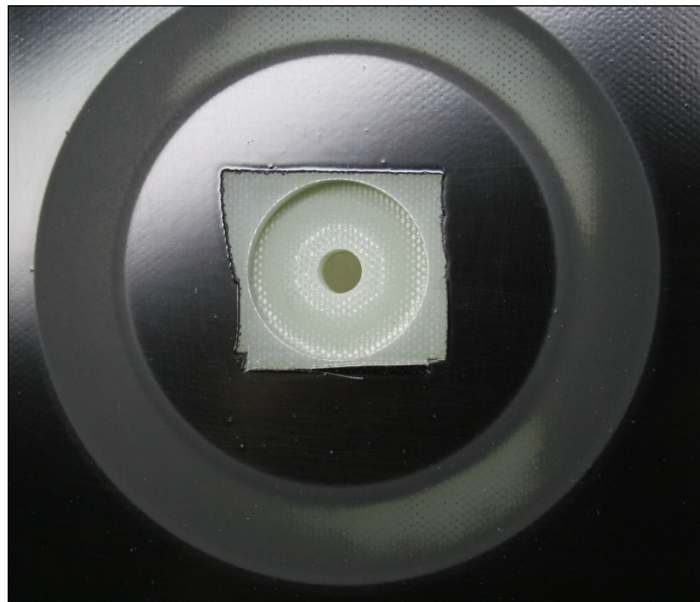


Figure 4. Rust-Oleum specialty appliance epoxy after 1500 cycles.

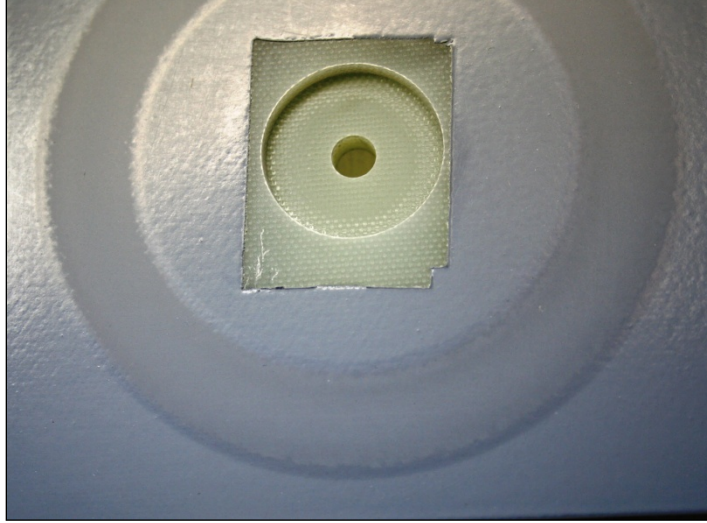


Figure 5. CeRam-Kote 54 ceramic epoxy after 6000 cycles.

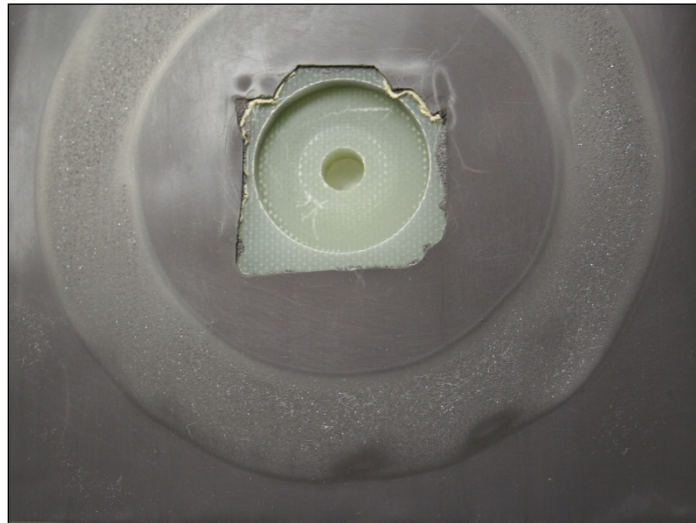


Figure 6. 3M FG-512 Scotchkote Epoxy Ceramic Surfacer after 6000 cycles.

Three samples per coating were prepared for this test series. Each sample was tested for 1000 cycles at a rotating speed of 60 cycles/min and then weighed. If the abrasion did not break through to the substrate, the sample was subjected to additional test intervals up to 6000 cycles and evaluated at 1000-cycle intervals. The wear index is 1000 times the loss in weight in milligrams per cycle (9). Wear index was determined for each test specimen by equation 1 (9). Figure 7 contains a summary of the wear index test results for the coatings in this series. The lower the wear index, the better the abrasion resistance of the coating. Rust-Oleum had an average wear index of 82 mg/cycle after 1000 cycles (figure 7). After approximately 1500 cycles, Rust-Oleum displayed significant breakthrough to the substrate (figure 4). The 3M FG-512 product had an average wear index of 42 mg/cycle after 1000 cycles and increased to 62-72 mg/cycle for test intervals 2000–6000 cycles (figure 4). After 6000 cycles, 3M FG-512 did not show any breakthrough to the substrate (figure 6). CeRam-Kote 54 had an average wear index of 20 mg/cycle after 1000 cycles and increased to 21–30 mg/cycle for test intervals 2000–6000 cycles (figure 7). After 6000 cycles, CeRam-Kote 54 did not show any breakthrough to the substrate (figure 5). The uncoated substrate had an average wear index of 10 mg/cycle after 1000 cycles and increased to 15 mg/cycle for test intervals 2000–6000 cycles (figure 7). Although the uncoated composite substrate had the lowest wear index, the application of any of the coatings will increase the operational life of the probe.

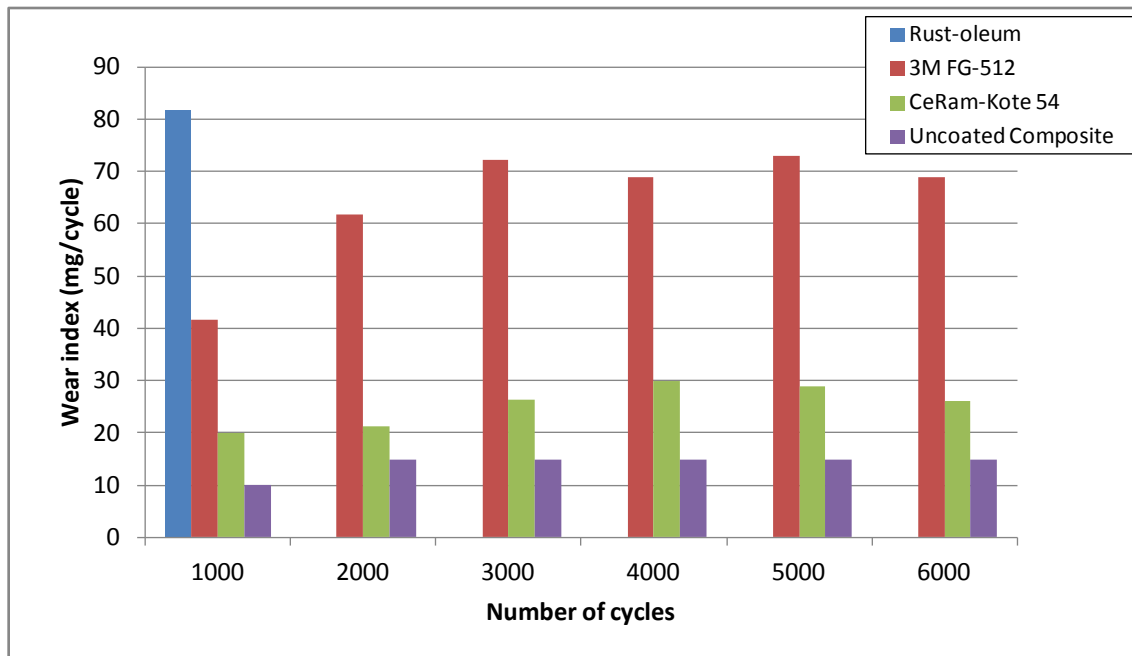


Figure 7. Summary of wear index test results.

*Wear index (9):*

$$I = \frac{(A-B)1000}{C} \quad (1)$$

*A* = weight of test specimen before abrasion (mg)

*B* = weight of test specimen after abrasion (mg)

*C* = number of cycles of abrasion recorded

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## 5. Conclusions

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Three commercial epoxy coatings were evaluated for abrasion resistance on FR-4 fiberglass epoxy composite with the Taber Abraser. The Rust-Oleum coating had the highest wear index (82 mg/cycle) and could not withstand more than 1500 cycles of abrasion testing. The 3M FG-512 coating had a better wear index (42 mg/cycle) than the Rust-Oleum and endured 6000 cycles of abrasion. The CeRam-Kote 54 product had the best wear index (20 mg/cycle) and survived 6000 cycles of abrasion testing. In addition, CeRam-Kote 54 is applied by spray and deposits a thin film, whereas the 3M FG-512 is applied via brush and leaves a slightly thicker uneven coating (figure 8). The thin film preserves the rigid sharp edge of the probe, while the irregularities of the 3M FG-512 may dull the edge and thus defeat the purpose. Therefore, we recommend CeRam-Kote 54 to be best coating to protect against the damaging effects of the abrasive components in soil and help extend the functional service life of the FR-4 composite probe. We also suggest placing probes coated with CeRam-Kote 54 into the field for assessment and comparison to uncoated probes.

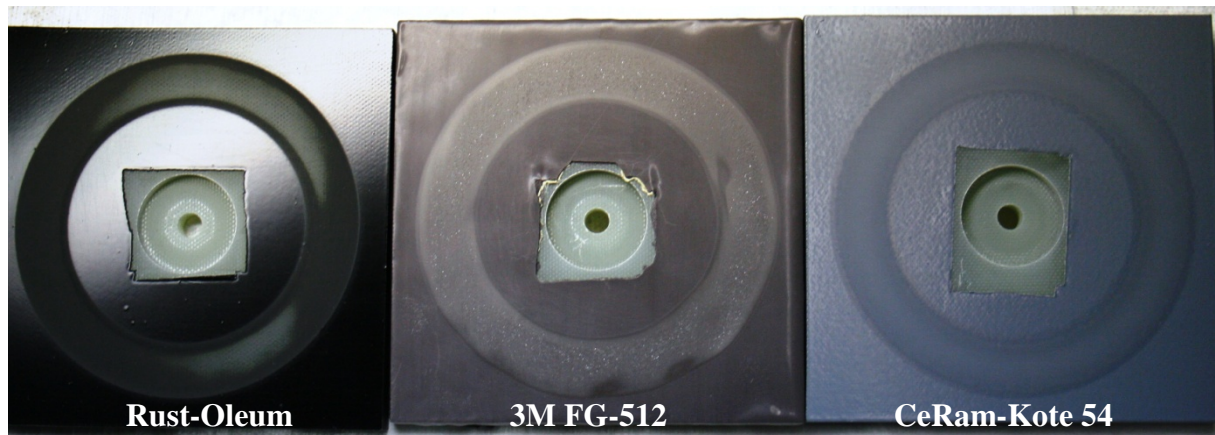


Figure 8. Commercial coatings in test series on fiberglass composite substrate.

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